Attenuated PSM for mitigating PSN effect in EUVL

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INTRODUCTION

Numerous challenges that EUVL currently faces!

EUVL currently faces numerous challenges including mask shadowing effect and photon shot noise effect. The mask shadowing effect is a unique phenomenon in the EUVL process and it is caused by the mirror-based mask structure and oblique incident angle of the light. In addition, the photon shot noise effect is the statistical fluctuations between photon and photo resist (PR). It has been understood that photon shot noise is a significant concern for EUVL due to its energetic photons. EUV light has 14.3 times higher energy than that of ArF light, and thus smaller number of photons that react with photo resist is required in EUVL for the same amount of dose, thus resulting in greater photon shot noise effect. These effects result in a patterning limit as well as critical dimension (CD) non-uniformity.

What is the mask shadowing effect?

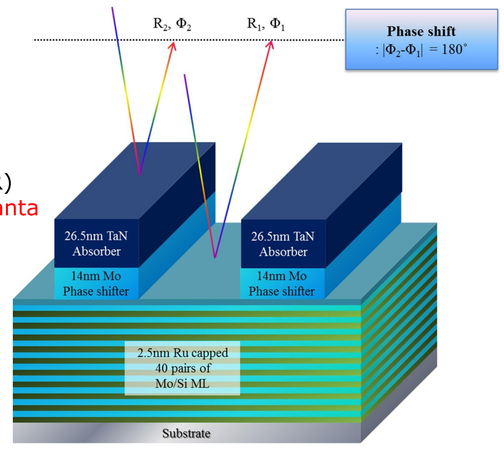
- The illumination beam is shadowed by edge of absorber
  - → The effective mask CD is changed.
  - → Printed pattern biased.

What is the photon shot noise effect?

- The statistical fluctuations between photon and photo resist (PR)
  - → Exposure dose & Diffraction Intensity ratio → number of quanta
  - → Small number of quanta → Large shot noise effect
  - → More serious for EUV lithography.
  - → Results in degradation of CDU, LER, LWR

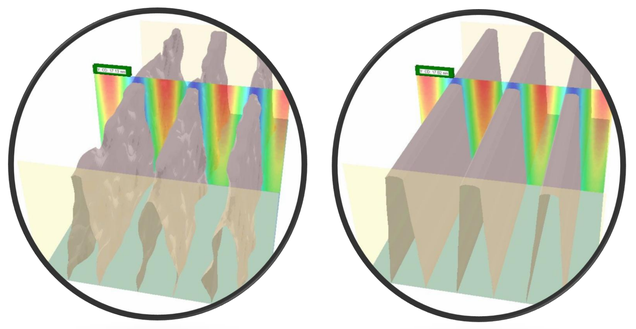
So, we propose attenuated Phase Shift Mask (att-PSM)!

- → 40.5nm absorber stack (26.5nm of TaN / 14nm of Mo)
- → ~6% reflectivity at absorber stack and 180° phase shift
- → Mitigate mask shadowing effect
- → Mitigate **photon shot noise effect (PSN effect)**

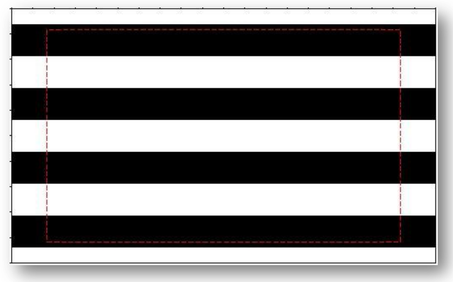


Schematic image of the proposed attenuated PSM

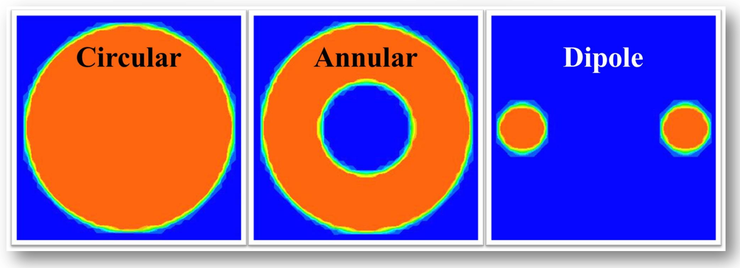
EXPERIMENT (Stochastic simulation by using PROLITH X4.1 of KLA-Tencor)



Stochastic resist simulation *vs.* *Continuum resist simulation*



18nm vertical(non-shadowing) 1:1 L/S pattern



off-axis illumination conditions
Circular (0.9σ), Annular (0.9, 0.4σ), Dipole (0.7σ, 0.2 radius)

Phase shift (ΔΦ) = (2πδ/λ)*Δr
(Δr = propagation distance)

Material	n	k
TaN	0.9260	0.0436
Si	0.9991	0.0018
Mo	0.9238	0.0064
Ru	0.8864	0.0171

Refractive index (n)= 1-δ + íβ

Optical constants of materials at 13.5nm

EQUATIONS (Way to mitigate PSN effect)

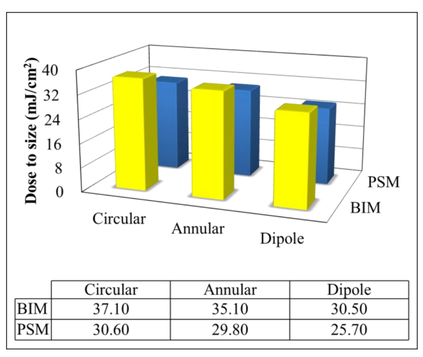
$$\mathrm{CDU}(3\sigma) \propto \frac{6}{\mathrm{ILS}}\frac{1}{\sqrt{N}} \quad \text{... (1)}$$

Where ILS is the image log slope and N is the number of photons absorbed in the exposed area. The equation shows PSN effect can be alleviated with increased ILS or increased number of absorbed photons.

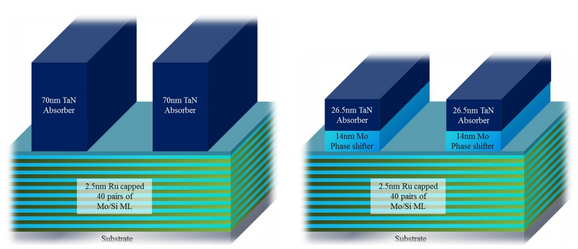
$$\mathrm{LER} \propto \frac{1}{\sqrt{N}} \quad \text{... (2)}$$

Line edge roughness (LER) and line width roughness (LWR) are strongly affected by photon shot noise effect. Decreased number of photons results in statistical variations causing line roughness of photo resist.

RESULTS & DISCUSSION (Absorbed photons between BIM and PSM)



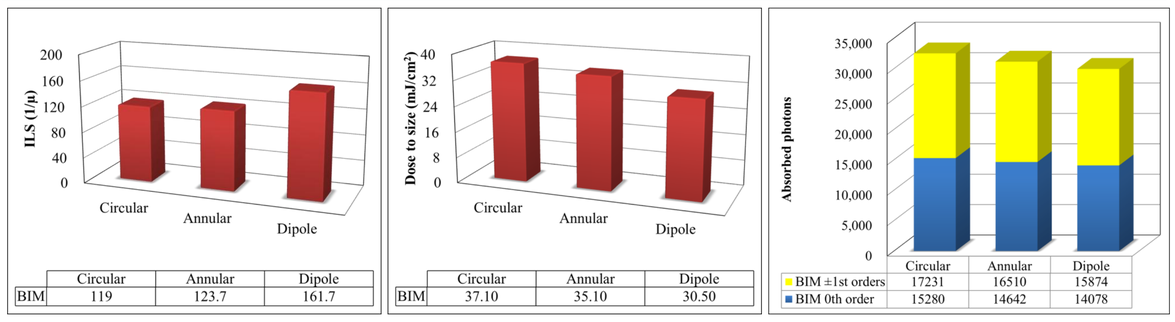
	Circular	Annular	Dipole
BIM	37.10	35.10	30.50
PSM	30.60	29.80	25.70



Comparison of dose to size between BIM and PSM *Comparison of absorber stack between BIM and PSM*

❖ As shown in this figure, the optimum dose to size for PSM is smaller compared to than that of BIM (e.g., 37.1mJ/cm2 and 30.6mJ/cm2 for circular illumination with BIM and PSM, respectively)

RESULTS & DISCUSSION (Using off-axis illuminations with BIM)



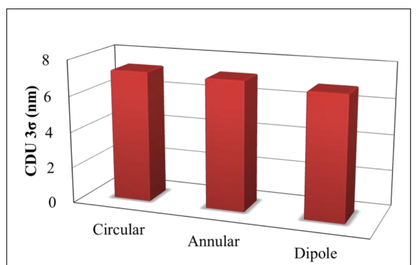
	Circular	Annular	Dipole
BIM	119	123.7	161.7

	Circular	Annular	Dipole
BIM	37.10	35.10	30.50

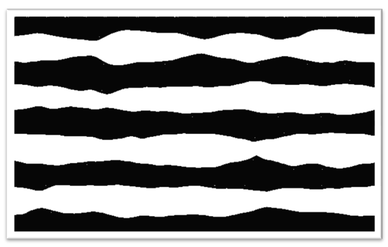
	Circular	Annular	Dipole
BIM ±1st orders	17231	16510	15874
BIM 0th order	15280	14642	14078

ILS, dose to size, absorbed photons as a function of off-axis illumination with BIM

❖ 18nm half-pitch using off-axis illumination with BIM is shown in left figure where ILS is increased, however results in middle figure show decrease of dose to size resulting less number of photons in exposed area consequently as right figure.



	Circular	Annular	Dipole
BIM	7.3	7.2	6.9

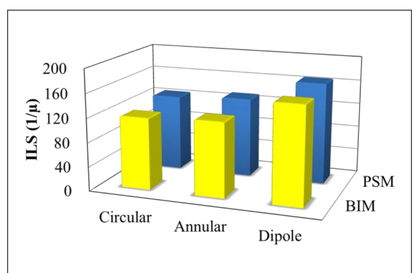


Developed PR image
(e.g., @ BIM, Circular illumination)

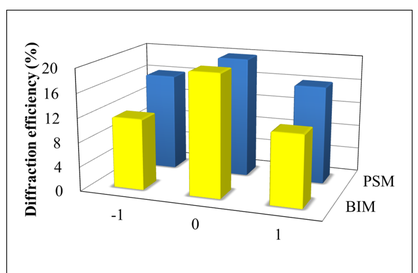
Local CD uniformity as a function of off-axis illumination with BIM

❖ In other words, increase in ILS and decrease in number of photons off set each other. Thus, off-axis illumination does not seem to mitigate photon shot noise effect as shown in this figure.

RESULTS & DISCUSSION (ILS & Diffraction efficiency between BIM and PSM)



	Circular	Annular	Dipole
BIM	119	123.7	161.7
PSM	126.6	132.1	167.7

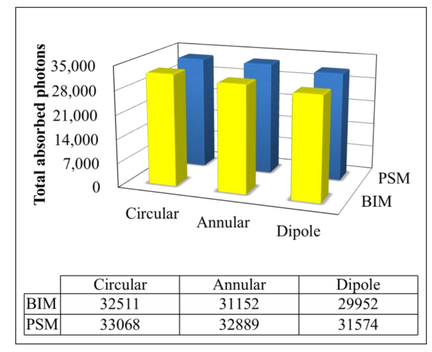


	-1	0	1
BIM	11.67	20.70	11.67
PSM	16.12	19.88	16.12

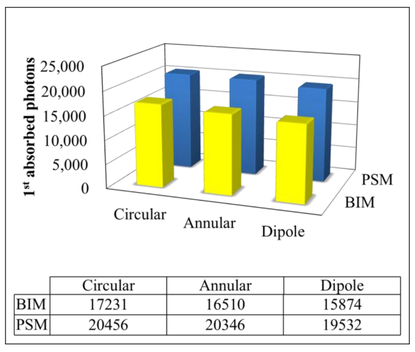
Types of mask	BIM	PSM
1st /0th orders ratio	1.128	1.622

Comparison of ILS and intensity of the diffraction orders between BIM and PSM

❖ Attenuated PSM was proposed to increase ILS and maximize intensity of diffracted photons (notably 1st orders) which helps transfer imaging information to the photo resist. And its optical performance was compared with that of a conventional binary intensity mask (BIM). This figure is the comparison of ILS and diffraction efficiency between BIM and PSM. As shown in the figure, the diffraction efficiency of 1st orders diffraction increased significantly with PSM.



	Circular	Annular	Dipole
BIM	32511	31152	29952
PSM	33068	32889	31574

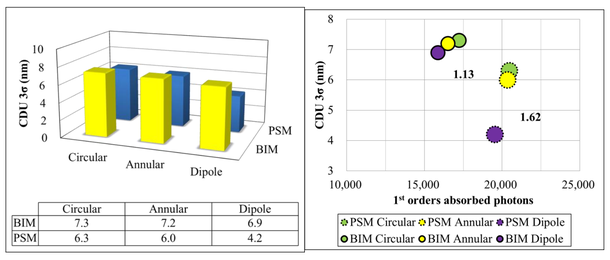


	Circular	Annular	Dipole
BIM	17231	16510	15874
PSM	20456	20346	19532

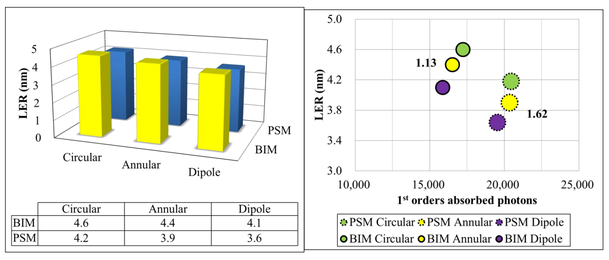
Comparison of total (0th+1st orders) absorbed photons and 1st orders absorbed photons between BIM and PSM

❖ However the total accumulated photons in the photo resist are larger for the PSM due to the increased intensity of the diffraction orders. Especially, PSM has noteworthy 1st /0th orders ratio compared to that of BIM and it can be concluded that there has been increase in informative photons due to the increase of intensity of 1st diffraction orders.

RESULTS & DISCUSSION (CDU & LER between BIM and PSM)



	Circular	Annular	Dipole
BIM	7.3	7.2	6.9
PSM	6.3	6.0	4.2



	Circular	Annular	Dipole
BIM	4.6	4.4	4.1
PSM	4.2	3.9	3.6

Comparison of CDU and LER between BIM and PSM
(The size of circle is 1st/0th orders ratio)

❖ CDU were decreased by 13.70%, 16.67% and 39.13% with circular, annular and dipole illumination conditions, respectively, when using PSM instead of BIM for 18nm L/S patterning. This improvement in CDU is mainly due to the increased diffracted photons with PSM structure as compares to BIM.

❖ LER is reduced by 9.13%, 11.36% and 11.22% using circular, annular and dipole illuminations, respectively. It is important to point out that the improvement in total 1/√N of absorbed photons for PSM is only about 0.85%, 2.67% and 2.60% compared to the conventional BIM using circular annular and dipole illuminations, respectively. On the other hand, 1/√N of 1st order diffracted photons for PSM was 8.21%, 9.92% and 9.85% lower than those of BIM, implying that LER is more affected by "informative" photons from 1st diffraction orders.

CONCLUSION

❖ Phase shift mask concept is newly proposed to improve CDU and LER caused by photon shot noise effect. It maximizes intensity of 1st order diffraction providing more informative photons that being transferred to the photoresist thus alleviating PSN effect

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